Kinetics of saccharose inversion (Artikelnr.: P3050301)

Curriculare Themenzuordnung

Fachgebiet: Chemie | **Bildungsstufe:** Hochschule | **Lehrplanthema:** Physikalische Chemie | **Unterthema:** Chemische Kinetik | **Experiment:**

Schwierigkeitsgrad	Vorbereitungszeit	Durchführungszeit	empfohlene Gruppengröße
Mittel	1 Stunde	1 Stunde	2 Schüler/Studenten

Zusätzlich wird benötigt:

Versuchsvarianten:

Schlagwörter:

Reaction rate, First order reaction, Polarimetry, Optical rotation

Overview

Short description

Principle:
The inversion reaction of saccharose, which is catalysed by protons, produces invert sugar, which is a mixture of glucose and fructose. The reaction is accompanied by a change in the optical rotation of the system. Glucose rotates the polarisation plane of linearly polarised light to the right, while inverted sugar rotates it to the left.
A half-shade polarimeter is used for the measurement of the change in the angle of rotation of polarised light during the inversion reaction of saccharose over time.

Safety instructions

Hydrochloric acid, 1 M
H290: May be corrosive to metals

Equipment

Position	Material	Bestellnr.	Menge
1	Half-shade polarimeter	35906-93	1
2	Immersion thermostat, 100 °C	08492-93	1
3	Accessory set for immersion thermostat	08492-01	1
4	Bath for thermostat, 6 l, Makrolon	08487-02	1
5	Rubber tubing, d(i) = 6 mm	39282-00	2
6	Hose clip, d = 8...12 mm	40996-01	3
7	Magnetic heating stirrer	35720-93	1
8	Magnetic stirrer bar, l = 15 mm	46299-01	1
9	Magnetic stirrer bar, l = 30 mm	46299-02	1
10	Support rod, l = 500 mm, M10 thread	02022-05	1
11	Right angle clamp	37697-00	4
12	Universal clamp	37715-00	3
13	Universal clamp with joint	37716-00	1
14	Stopwatch, digital, 1/100 s	03071-01	1
15	Precision balance, 620 g	48852-93	1
16	Weighing dishes, 80×50×14 mm	45019-05	1
17	Volumetric pipette, 10 ml	36578-00	7
18	Pipettor	36592-00	1
19	Pipette dish	36589-00	1
20	Pasteur pipettes	36590-00	1
21	Rubber bulbs	39275-03	1
22	Volumetric flask, 50 ml	36547-00	2
23	Volumetric flask, 500 ml	36551-00	1
24	Glass beaker, 100 ml, tall	36002-00	10
25	Crystallisation dish, 1000 ml	46245-00	1
26	Funnel, glass, d(o) = 55 mm	34457-00	1
27	Spoon	33398-00	1
28	Wash bottle, 500 ml	33931-00	1
29	D(+)-Saccharose, extra pure, 100 g	30210-10	1
30	D(+)-Lactose, 100 g	31577-10	1
31	Hydrochloric acid for 1 l of 1 M standard solution, 1 ampoule	30271-00	1
	Water, distilled, 5 l	31246-81	1

Task

Set-up and procedure

Set-up

Set up the experiment as shown in Fig. 1.
Prepare the solutions required for the experiment as follows:

- 2 molar HCl solution: Pour the contents of the ampoule (for 1 l of 1 M hydrochloric acid) into a 500 ml volumetric flask and fill up to the calibration mark with distilled water.
- Saccharose solutions: Weigh 12.000 g of saccharose into a 50 ml volumetric flask, dissolve it in distilled water, and fill up to the calibration mark with distilled water (c = 0.24 g/cm^3). Transfer the solution into a 100 ml beaker. Pipette 10 ml of the solution into a second glass beaker and add 10 ml of water (c/2). Prepare solutions of concentrations c/4 and c/8 by pipetting 10 ml each of the c/2 and c/4 solutions into two further glass beakers and adding 10 ml of water.
- Lactose solutions: Weigh 1.500 g of lactose into a 50 ml volumetric flask, dissolve it in distilled water, and fill up to the calibration mark with distilled water (c = 0.030 g/cm^3). Prepare solutions of concentrations c/2, c/4 and c/8 from this as for saccharose.

Fig. 1

Procedure

Temperature equilibrate the sugar solutions to 20 °C in a temperature- controlled bath. Use a polarimeter to measure the angle of rotation of the solutions. The apparatus first polarises the vibration plane of monochromatic light (λ = 589.9 nm, sodium- D-line) linearly. This polarised light then passes through a cell containing the solution to be measured. Optically active substances in the solution change the polarisation plane of the light. The polarimeter analyser must be so adjusted that both semicircles visible in the ocular have the same level of brightness. The angle of rotation can then be directly read from the scale.

- To investigate the kinetics of saccharose inversion, warm the saccharose solution of concentration c = 0.24 g/cm^3 and the 2 molar hydrochloric acid solution to 30 °C in the temperaturecontrolled bath.
- Pipette 10 ml of the warm saccharose solution into a 100 ml beaker and add 10 ml of hydrochloric acid. Start the stopwatch.
- Fill the polarimeter cell bubble-free with the acidified saccharose solution and hang it into the thermostatic bath. In due good time remove the cell from the bath, dry its exterior surface, and after exactly 5 minutes determine the angle of rotation (α_t).
- Again temperature equilibrate the cell and take a value every 5 minutes, following the same procedure as above. Stop the measurement series after 50 minutes.
- Parallel to this, mix 10 ml saccharose solution of concentration c = 0.24 g/cm^3 and 10 ml of 2 molar hydrochloric acid solution in a 100 ml beaker and heat it to 70 °C on a magnetic heating stirrer, using a 600 ml beaker as water bath. After 10 minutes, temperature equilibrate it in the thermostatic bath to 30 °C and then measure the angle of rotation (α_∞).

Theory and evaluation

Theory:
Optical activity is the ability of certain substances to rotate the plane of vibration of linearly polarised light. When linearly polarised light passes through such a substance, the radiation components are shifted in phase due to the interaction of substances which contain asymmetric carbon atoms. This phase shift is seen as a rotation of the plane of polarisation.
The specific rotation of optically active solutions is defined as that angle at which the plane of vibration of sodium-D-light $(\lambda = 589.9\,\mathrm{nm})$ is rotated when the thickness of the layer of the solution is 100 mm, 1 g of substance is dissolved in 1 cm^3, and the measurement is undertaken at a temperature of 20 °C.
The angle of rotation α is proportional to the concentration *c* of the dissolved substance. The specific rotation $[\alpha]_D$ can be so determined by testing solutions of known concentration:

$$[\alpha]_D^{20} = \frac{\alpha}{c} \quad (1)$$

If the temperature of measurement ϑ deviates from 20 °C, the result can be converted to this temperature by using equation (2) for lactose and equation (3) for saccharose:

$$[\alpha]_D^{20} = [\alpha]_D^{\vartheta} - 0.072 \cdot (20^\circ\mathrm{C} - \vartheta) \quad (2)$$

$$[\alpha]_D^{20} = \frac{[\alpha]_D^{\vartheta}}{1 - 0.00037\,(\vartheta - 20^\circ\mathrm{C})} \quad (3)$$

In an acidic environment, saccharose undergoes hydrolytic cleavage into glucose and fructose, in a process catalysed by oxonium ions. Dextrorotatory saccharose is converted into dextrorotatory glucose and laevorotatory fructose (Fig. 2).

$$\underset{[\alpha]_D^{20} = +66.5^\circ}{\text{sucrose}} + \mathrm{H_2O} \xrightarrow{[\mathrm{H_3O^+}]} \underbrace{\underset{[\alpha]_D^{20} = +52^\circ}{\text{gulcose}} + \underset{[\alpha]_D^{20} = -92^\circ}{\text{fructose}}}_{\substack{\textit{invert sugar} \\ [\alpha]_D^{20} = -20^\circ}}$$

Fig. 2

Overall, this reaction corresponds to a pseudo-first order reaction, i.e. the reaction rate depends only on the saccharose concentration.

$$-\frac{\mathrm{d}c}{\mathrm{d}t} = k \cdot c \quad (4)$$

The rate of reaction is defined as the change in concentration d*c* per unit of time d*t*. The reaction rate decreases with the concentration *c*. The proportionality factor of this relationship is the rate constant *k*, which is characteristic for a specific reaction. Integration of (4) results in:

$$\ln\frac{c_0}{c} = k \cdot (t - t_0) \quad (5)$$

where c_0 is the initial concentration at time $t_0 = 0$ and $c(t)$ is the concentration at time *t*.
A change of the concentration corresponds to a change of the angle of rotation.

$$\ln\frac{c_0}{c} = \ln\frac{\alpha_0 - \alpha_\infty}{\alpha_t - \alpha_\infty} \tag{6}$$

where at is the angle of rotation at time *t*, α_0 is the angle of rotation of pure saccharose solution, and α_∞ is the angle of rotation when hydrolysis has been completed. Taking equation (5) into account, it follows that

$$k = \frac{1}{t} \cdot \ln\frac{\alpha_0 - \alpha_\infty}{\alpha_t - \alpha_\infty} \tag{7}$$

k can also be calculated from the slope $\frac{1}{k}$ of the straight line resulting from

$$t = \frac{1}{k} \cdot \ln\frac{\alpha_0 - \alpha_\infty}{\alpha_t - \alpha_\infty} \tag{8}$$

Results:

Fig. 3 shows the experimental values obtained for $c_0 = 0.12\,\frac{\mathrm{g}}{\mathrm{cm}^3}$ and 30 °C. They result in a rate constant of $k = 2.5 \cdot 10^{-2}\, min^{-1}$.

Literature values:

Glucose:	$[\alpha]_D^{20} =$	+52.5	to	+53.0
Fructose:	$[\alpha]_D^{20} =$	−91.0	to	−93.5
Lactose:	$[\alpha]_D^{20} =$	+52.2	to	+52.8
Saccharose:	$[\alpha]_D^{20} =$	+66.2	to	+66.8

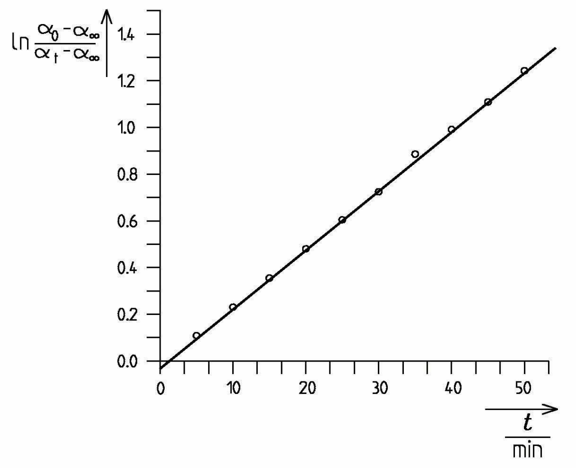

Fig. 3